An Automated Real-Time PIXON Pipeline for the IRTF

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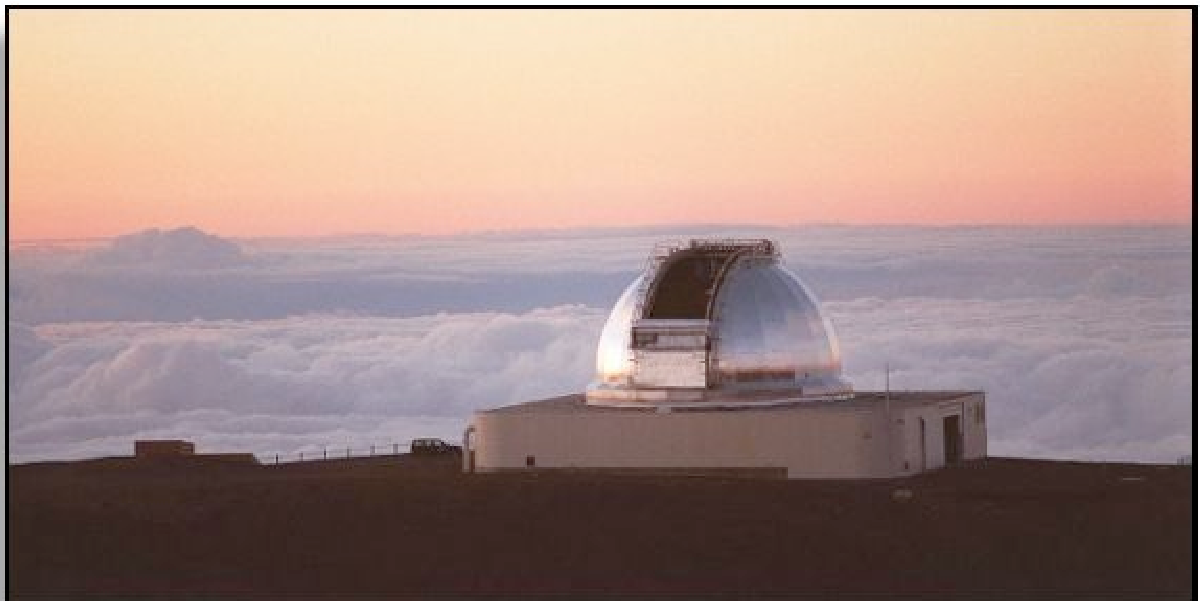
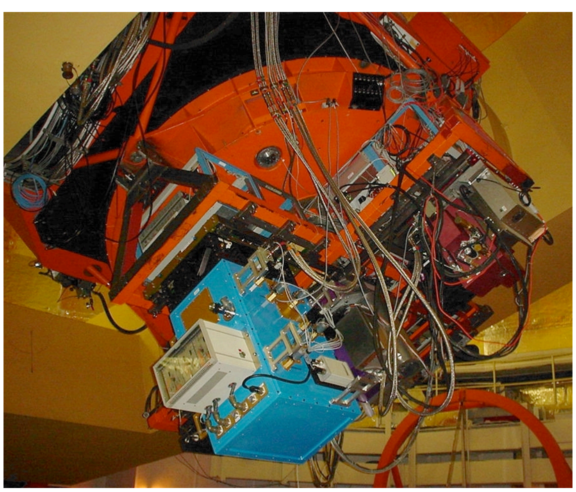


Photo: John Spencer



SpeX: A Medium-Resolution 0.8-5.5 micron Spectrograph and Imager for the NASA Infrared Telescope Facility

J. T. Rayner, D. W. Toomey, P. M. Onaka, A. J. Denault, W. E. Stahlberger, W. D. Vacca, M. C. Cushing and S. Wang (2003, *PASP* **115**, 362).

Coming soon to the IRTF... NSFCAM2 with AO (adaptive optics).

IRTF PIXON PIPELINE: One-Page Cheat-Sheet

BASIC GOAL: Automatically sharpen IRTF images using PIXON deconvolution. *No user expertise necessary.*

BASIC STEPS

1. Preprocess images

  1.1. Standard dark & bias subtraction and flat field normalization.

  1.2. Background estimation and removal.

  1.3. Bad pixel identification.

  1.4. Pixel-by-pixel noise estimation – CRITICAL STEP!

2. Determine the Point Spread Function (PSF)

  2.1. Estimate PSF from on-chip point sources.

  2.2. Start with an educated guess for the PSF and iteratively improve.

3. Apply PIXON reconstruction, subject to the following constraints

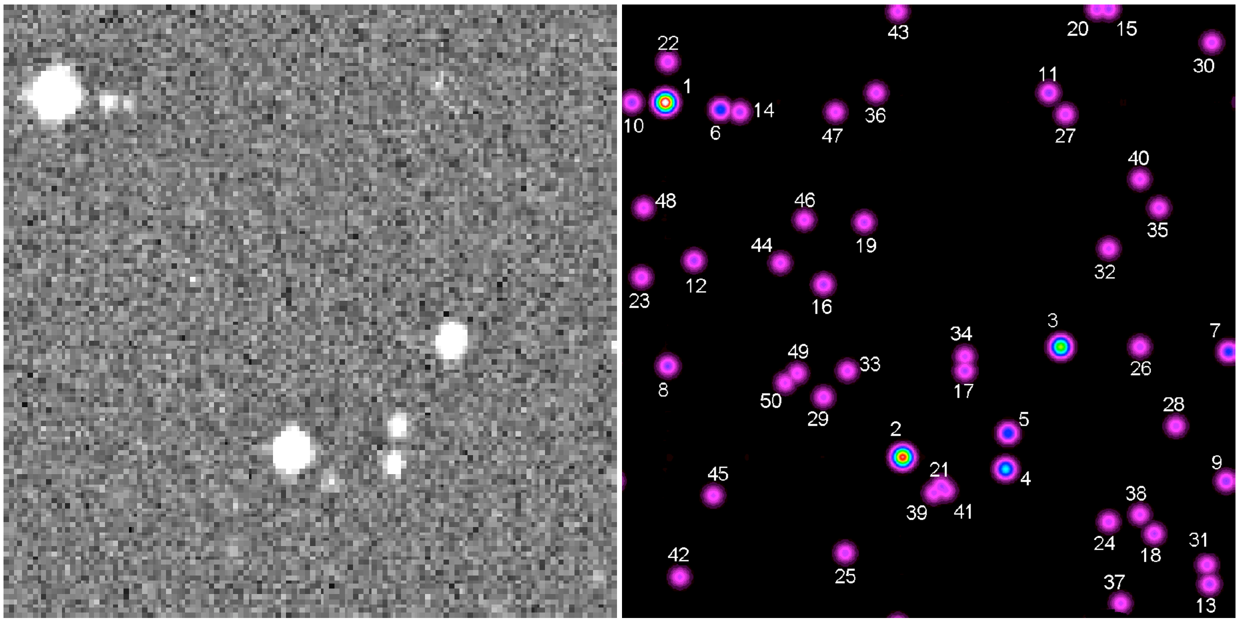
  3.1. Quality of the fit (data - model) is reasonable, otherwise the PSF or the noise estimates are probably wrong.

  3.2. In addition to the *magnitude* of the residuals (per degree of freedom) being reasonable, the spatial distribution of residuals has to be random, free of patterns.

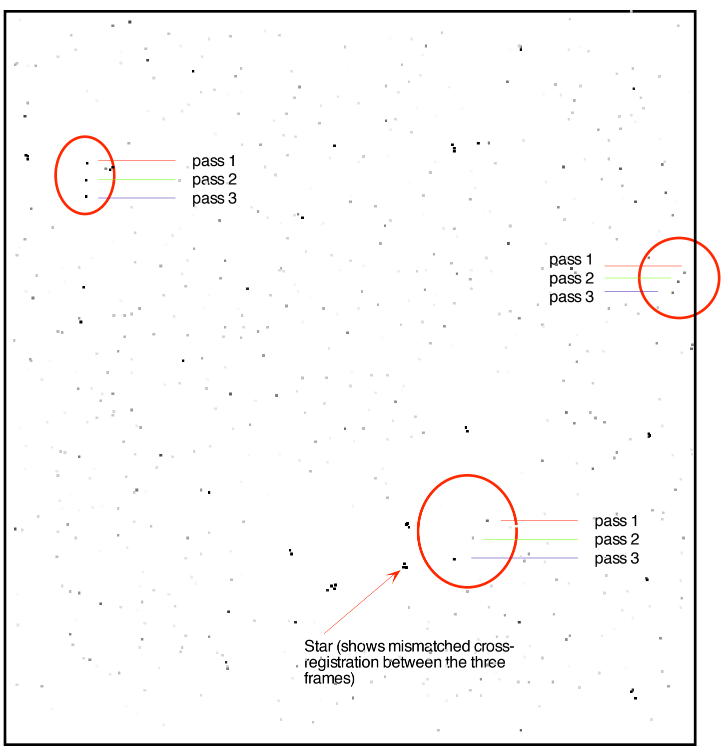
THE PIXON ALGORITHM makes guesses for the true image. It seeks the *simplest* image that, when convolved with the PSF, produces a model that differs from the data (at each pixel) by an amount that is consistent with the noise estimates.

MOTIVATION (Why bother with image enhancement?)

An Example: Spacewatch Data



An individual SPACEWATCH exposure (left) and sources (right) found by PIXON.



A triplet of exposures in this 128 x 128 subframe shows THREE asteroid discoveries that were below the threshold of the unprocessed data.

For typical seeing at the IRTF, careful PIXON processing should lead to a magnitude im–provement in the detection limit. That improvement will double the number of asteroid detections per frame.

PREPROCESSING

(Not part of our original proposed task list, but so integral to PIXON or Lucy-Richardson deconvolution that we have to include it as part of the pipeline.)

Every Instrument has Unique Characteristics

SpeX has an imager (called “GuideDog”) and a spectrograph (“BigDog”). GuideDog images have alternating row “picket fence” gain variations and noisy 8th columns if fast readout modes are used.

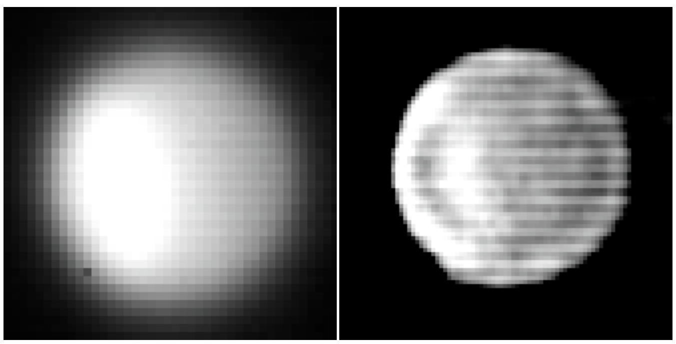
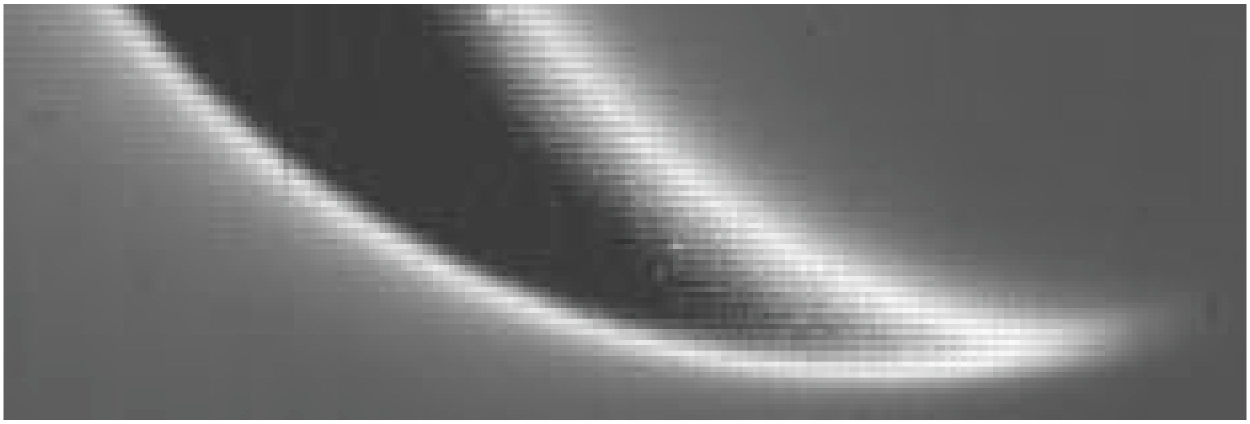


FIG. 7
A comparison between the original image (LEFT) and the PIXON-processed image. The enhanced image shows a sharper limb and resolves the bright region on the left pole into separate bright structures. The alternating row pattern is an artifact of the instrument read-out.

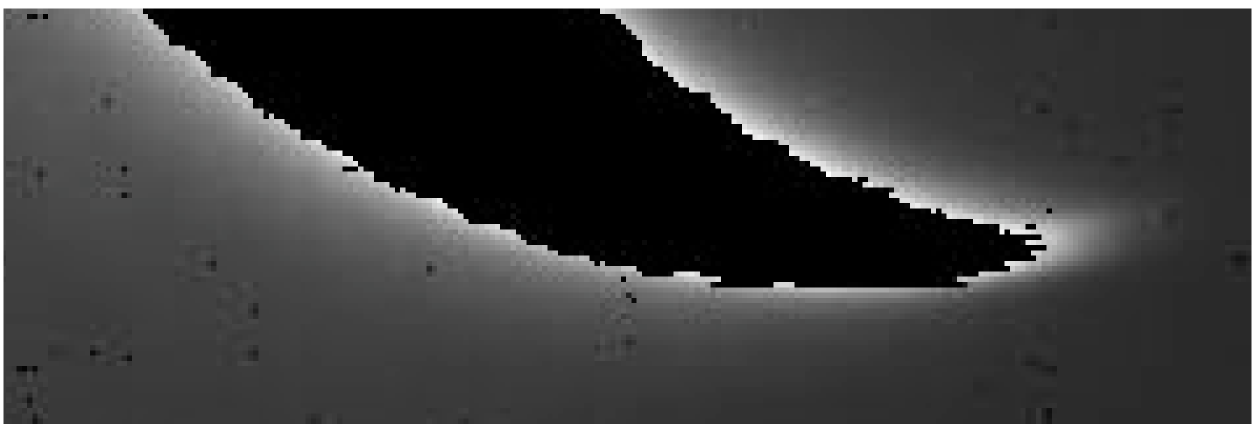
Making GuideDog flats is a challenge. We recommend a series of sky exposures at various integrations, and a linear fit to the pixel values to make a gain map at each pixel. Operationally, this will be a macro under the SpeX GUI that a user should select.

Raw image (Venus) Flat field Flattened image

Status: Flat fielding problem seems to be solved.



Original Image



Flat-fielded image (and saturated pixels masked off)

MORE PREPROCESSING

Noise estimation: several codes available (DAOPHOT, SEXTRACTOR), all of which (a) assume that the noise has a gaussian distribution and (b) iteratively fit the background pixels, masking the outliers in each iteration.

Conveniently, SpeX engineers have written up the noise characteristics of the SpeX arrays.

Nonlinearity Corrections and Statistical Uncertainties Associated with Near-Infrared Arrays

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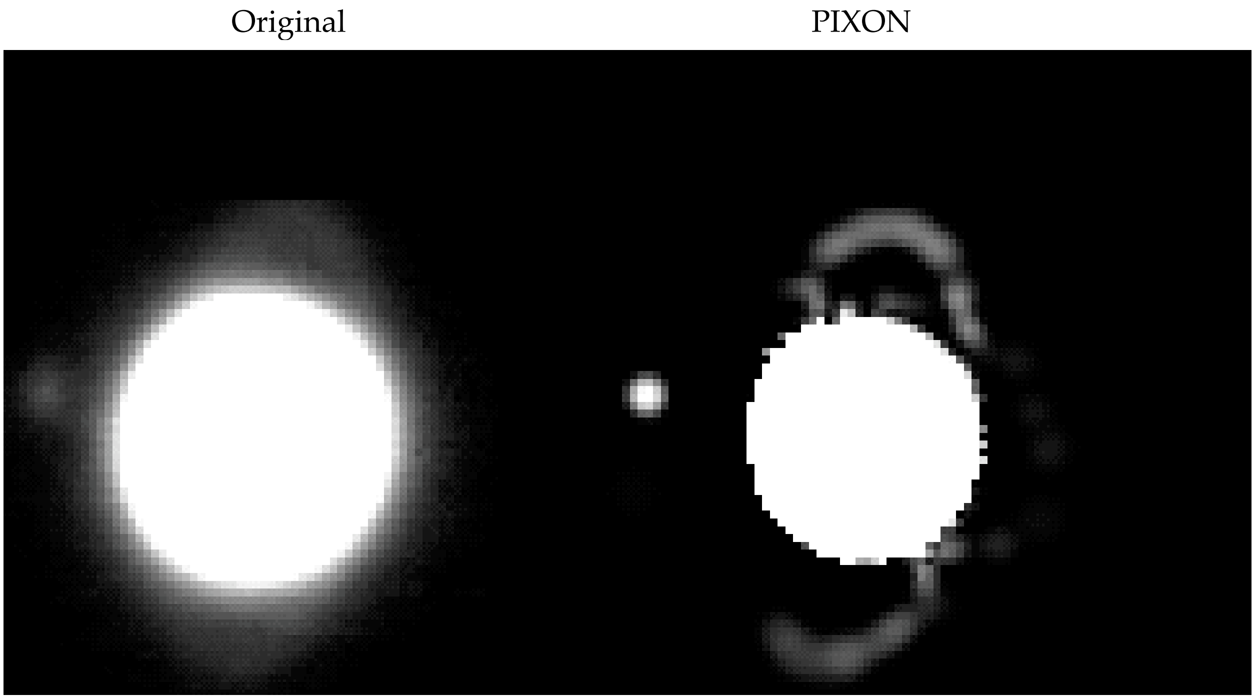
ABSTRACT. We derive general equations for nonlinearity corrections and statistical uncertainty (variance) estimates for data acquired with near-infrared detectors employing correlated double sampling, multiple correlated double sampling (Fowler sampling), and uniformly spaced continuous readout techniques. We compare our equation for the variance on each pixel associated with Fowler sampling with data taken with the array installed in the near-infrared cross-dispersed spectrograph (SpeX) at the NASA Infrared Telescope Facility and find that it provides an accurate representation of the empirical results. This comparison also reveals that the read noise associated with a single readout of the SpeX array increases with the number of nondestructive reads, n_r, as $n_r^{0.16}$. This implies that the *effective* read noise of a stored image decreases as $n_r^{-0.34}$, shallower than the expected rate of $n_r^{-0.5}$. The cause of this read noise behavior is uncertain but it may be due to heating of the array as a result of the multiple readouts. Such behavior may be generic to arrays that employ correlated or multiple correlated double sampling readouts.

Vacca, Cushing and Rayner (2004) present straightforward expressions for the noise for different read-out modes (multiply correlated double sampling, or MCDS).

NOTE: One of the main “knobs” to twiddle in the PIXON algorithm is called “anneal.” Its function is to scale the estimated noise. High values of anneal produce smoother images, since details aren’t significant compared to the high noise levels. A typical PIXON strategy is to gradually increase anneal until the residuals are large compared to the real noise.

GOOD PSFs ARE HARD TO FIND...

Our biggest remaining challenge is getting accurate PSFs. Even on-chip point sources aren't good enough. (Example: H-band image of Uranus deconvolved with Umbriel.)



A really accurate PSF would bring out the uranian rings WITHOUT requiring the artifacts in the glare around the disk.

Current Work: A good PSF has some constraints.

1. Positivity.
2. The deconvolved image may have a region of support (e.g., no flux outside of Uranus's disk).
3. Includes the PSF of the optics pathway.
4. Spatial frequency low-pass cut-off for the PSF (to help prevent delta-function PSFs).

Currently using the IDAC package. Note that item (3) is often the most useful, which is why we've implemented (several) speckle routines. The user runs a macro to obtain thousands of fast exposures of a nearby bright star, and our routines extract an instrumental PSF.